The Effect of Interocular Distance upon Operator Performance using Stereoscopic Displays to Perform Virtual Depth Tasks.

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ABSTRACT

When implementing a stereoscopic vision system for telepresence or virtual environment systems, many questions arise regarding the design parameters governing artificial stereopsis. Although many designers choose parameters that most closely match human physiology, it is not clear that such choices optimize operator performance or enhance the understanding of information displayed. This study investigates a basic parameter governing stereopsis; *interocular distance*, and assesses its effect upon operator performance in a binocular depth perception task. Subjects were required to visually align *virtual* pegs as presented by a stereoscopic display. Interocular distance of the projection model was varied between 0cm and 8cm for each alignment trial. Results revealed a ten fold increase in depth perception performance when stereoscopic projections were provided rather than monocular projections. A roughly logarithmic relation was found between interocular distance and operator performance. As interocular distance increased from 0 cm to 2 cm, performance improved rapidly then asymptotically approached a maximum value. Although average physiological interocular distance is 6.3 cm, no measurable increase in performance was found for interocular distances greater than 3 cm. The relation between interocular distance and performance suggests that the use of stereoscopic projections rather than monocular projections greatly enhances performance in depth perception tasks. It further suggests that there is no advantage to using physiologically typical values of interocular distance when projecting stereoscopic images. Because reduced disparity in stereoscopic projections typically increases displayable depth range, reduces image fusion problems, and reduces operator fatigue, there is a strong motivation to use smaller than physiological values of interocular distance in the projection of stereoscopic images. This study suggests that interocular distances as small as 2 or 3 cm may not degrade performance in depth tasks and may facilitate stereoscopic projections.

INTRODUCTION

It is well known that binocular stereopsis enhances performance in depth perception tasks [1]. Although much depth information can be inferred from monocular depth cues alone, stereoscopic depth cues provide additional information that often enhances the speed and accuracy of tasks requiring depth perception. When considering the use of stereoscopic vision as part of the user interface for telepresence or virtual environment systems, questions arise regarding the design parameters for implementing artificial stereopsis. Visual projection technologies used in telepresence and virtual environment systems offer new freedom from the biological constraints on stereoscopic vision. Many of the parameters of human vision which could not have been optimized or even altered in the past have suddenly become design parameters. This study investigates a basic parameter of stereoscopic vision, interocular distance, and assesses its effect upon performance in depth perception tasks. Although average physiological eye separation is 6.3cm [2] , the use of such a value may not yield maximal operator performance in virtual depth tasks. This study develops a relation between interocular distance and operator performance in depth tasks.

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Previous studies have presented conflicting results comparing stereoscopic and monocular projections of visual information. Many studies have shown that stereoscopic displays of remote worksites do not provide significant performance advantage over monocular projections [3,4,5,6]. Other studies have indicated that performance associated with stereoscopic displays is greatly superior than monocular displays [7,8,9,10,11]. This study attempts to gain insight into this issue by comparing monocular and stereo projections not as binary alternative conditions but rather by comparing a full range of interocular distances from pure monocular to exaggerated stereo.

EXPERIMENTAL PROCEDURE

Virtual Peg Alignment Task:

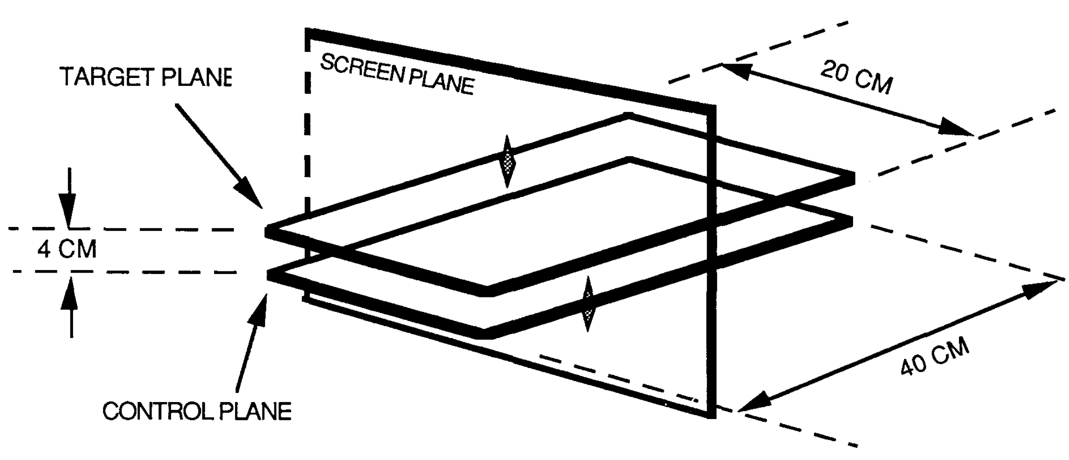
Each subject was outfitted with liquid crystal shuttering glasses and seated 80±4 cm from the face of a graphic display monitor. Subjects were presented with stereoscopic renderings of two *virtual pegs* on a blue background. Both pegs were modeled identically as three dimensional diamond shaped solids 3.5 cm high and 0.8 cm wide. The pegs were rendered and shaded as realistic objects to provide monocular depth cues in addition to the stereo cues. The use of simple, perceptually rich figures on a sparse background provided a controlled but realistic perceptual environment for testing. One of the pegs was defined as the *target peg* and was placed by the computer at a random location in a plane called the TARGET X-Z plane (a horizontal plane into the monitor). The other peg was defined as the *control peg*. and was positioned by the subject using a standard mouse interface. The subject could move the control peg anywhere in a plane parallel to the TARGET X-Z plane called the CONTROL X-Z plane. These two parallel planes were defined identical in size, being 20 cm wide and 40 cm deep as shown in figure 1. The TARGET X-Z plane was positioned 2 cm above the center point of the screen and the CONTROL X-Z plane was positioned 2 cm below the center point of the screen. Restricting peg motion to these parallel planes guaranteed the bottom of the target peg to be located the same distance (as seen in stereo perspective) above the top of the control peg and thus eliminated vertical displacement between the pegs as a variable in this study.

Experimental Protocol:

Each trial was run as follows: The computer placed the target peg somewhere on the TARGET X-Z plane and projected the stereoscopic image using a particular interocular distance in the projection model. The subject was then instructed to use the mouse to position the control peg so it was aligned directly below the target peg. Since movement of the control peg was constrained to the CONTROL X-Z plane, vertical alignment was guaranteed. The subject was provided with as much time as required to line up the pegs along the X and Z axes. When satisfied with alignment, the subject pressed a button on the mouse and the trial was complete. For each trial the computer recorded the target peg position, the control peg position, the time taken for the trial, and the interocular distance used in the projection model for that trial.

For each of 9 subjects tested, 90 trials were run. Each trial tested a particular target peg position and projected the image with a particular interocular distance. All subjects were tested on the same distribution of target location/interocular distance pairs. Interocular distances ranging from 0 cm to 8 cm were tested, yielding a full range of images from pure monocular to exaggerated stereo. The use of graphical simulation for these peg alignment tests allowed for rapid and discrete variation of interocular distance between trials. Target locations were randomly mixed as were interocular distance. Thus the subjects had no way to predict peg location in subsequent trials and had no knowledge of the interocular distance used for each projection. In fact, subjects were not informed that interocular distances were being varied during the experiment to insure that such knowledge would not influence performance.

Figure 4



Target Plane and Control Plane shown in relation to the plane of the video screen. Peg positions are restricted to their respective planes.

Figure 1: Test Setup for Virtual Peg Alignment Task

RESULTS

For each trial of each test, the following information was recorded: target peg positions, control peg positions, interocular distance used in the trial, and elapsed time for the trial. Alignment errors were computed by subtracting the coordinates of the target peg from the coordinates of the control peg. The values were then grouped by the interocular distance so that performance could be correlated to eye separation used in the projection model. Mean alignment errors and standard deviations of alignment errors were generated for each interocular distance as shown in Figure 2.

DISCUSSION

Considering mean alignment error, a surprising relation between performance and interocular distance is revealed. Figure 2 shows a plot of mean alignment error (along depth axis) vs interocular distance across all subjects. As was expected, this plot shows a marked degradation in performance as interocular distance approaches zero. In fact, when an interocular distance of 0 cm was used in the projection model (corresponding to monocular vision) , the mean error was roughly 10 times greater than when a physiologically typical interocular distance of 6 cm was used. These results strongly support the use of stereo projections over monocular projections to improve performance in depth perception tasks. It should be noted that the peg alignment task made use of three-dimensionally rendered and shaded pegs to assure the presence of rich monocular depth cues. During post-testing interviews, many subjects reported that size variation with depth was a cue that they consciously used in depth alignment. Although subjects reported to use this monocular depth cue as a guide when performing this task, performance in trials with adequate stereopsis greatly surpassed performance in trials with little or no stereoscopic cues.

This result suggests that stereoscopic vision enhances performance in depth perception tasks even when monocular depth cues are provided to the user.

If a curve is fit to the depth performance data displayed in Figure 2, a logarithmic relation between mean alignment error and interocular distance emerges. Although this logarithmic relation predicts dramatic degradation in performance when interocular distances drops below 2 cm, very little change in performance is seen over the rest of interocular distance range tested. In fact, no measurable increase in mean depth perception performance was noted for interocular distances greater than 3 cm. Although the logarithmic curve was fit for mean data across all subjects, analysis of each subject's performance in isolation demonstrated that individual subjects displayed the same effect.

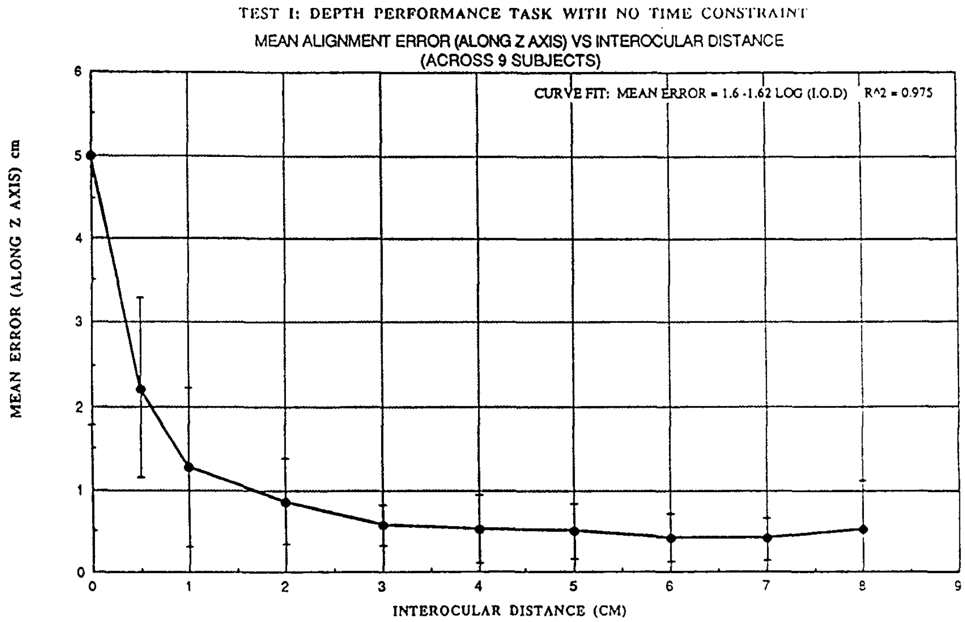


Figure 2: Mean Alignment Error vs Interocular Distance (all 9 Subjects)

Results of this study suggest that any interocular distance greater than about 3 cm can be use in the projection model without compromising performance in simple depth perception tasks. This result alone is not of much significance unless there is a motivation for using particular values of interocular distance in the projection model. Such a motivation does exist; the range of depths that can be presented to a user is greatly limited by a users ability to fuse the image pair. If images are projected too far behind or in front of the plane of the screen, disparity become so large that the user can no longer fuse the pair and a double image appears [12]. This is the same double image effect that occurs if you hold your finger too close to your eyes. Since the magnitude of disparity is a function of interocular distance, the smaller the value of interocular distance used, the greater the range of depth can be achieved without loss of image fusion.

Another motivation for using smaller than physiological values of interocular distance stems from the fact that although the visual system perceives the object at some depth in front of or behind the screen, the eyes must remained accommodated on the plain of the screen to accurately resolve the display [12]. This contradiction between focal depth and perceived depth can cause

user discomfort and fatigue. This effect is often relieved by reducing image disparity. Since disparity is scaled by interocular distance, reducing the interocular distance in the projection model is an effective method of combatting this fatigue effect.

CONCLUSIONS

When presenting virtual images to a user performing a simple task requiring depth perception, the use of stereoscopic projections resulted in a 10-fold reduction in mean alignment error as compared to the use of monocular projections. Although average physiological interocular distance is 6.3 cm, it was found that any interocular distance of greater than 3 cm used in the stereo projection model was adequate to provide a user with maximal performance in the depth perception task. No statistically significant increase in performance could be correlated to increasing interocular distances greater than 3 cm. Since it is often beneficial to reduce retinal disparity between the left and right images to increase the presentable depth range, reduce image fusion problems, and reduce operator fatigue, these results suggests that smaller than physiological interocular distances should be considered when implementing a stereoscopic vision system for virtual environments and telepresence systems.

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